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MASTER

TITLE INTEGRATION OF MULTIPLE DATA SETS FOR RESOURCE EVALUATION OF THE MONTROSE 1^{o} x 2^{o} QUADRANGLE, COLORADO

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ABSTRACT

At Los Alamos National Laboratory, geoscientists have assembled and integrated 30 geological, geochemical, and geophysical data sets with 4 Landsat bands for the Montrose 1° x 2° quadrangle, Colorado. A graphical presentation, which allows three data sets to be viewed simultaneously, is employed to facilitate the interpretation. Analysis of one of the three-data-set combinations (copper, lead, zinc) defines, spatially and geochemically, all the mining districts in the quadrangle and yields new information relating to base and precious metal mineralization. Analysis of two other three-data-set combinations (dysprosium, hafnium, scandium; and potassium, lithium, titanium) indicates that the granites in the Sawatch Range are of different trace-element composition (and therefore, possibly of different origin) than the granites in the Mosquito Range. This technique permits rapid analysis of tremendous amounts of data and the inference of correlative information that is not inherent in single data sets.

INTRODUCTION

At Los Alamos National Laboratory, geoscientists have assembled and integrated 30 geological, geochemical, and geophysical data sets with 4 Landsat bands for the Montrose quadrangle, Colorado. Originally interpreted to identify areas in the quadrangle with potential for uranium mineralization (Bolivar and others, 1981), further interpretation of these data has yielded new information regarding base and precious metal mineralization in the quadrangle and the structural relations of Precambrian granites in the area. These observations and interpretations are discussed herein.

Even in the Geosciences, data do not become knowledge until analyzed. At the rate geologic data are being collected, evaluation of all available data relating to any given problem is rapidly becoming impossible. In the United States alone, programs such as the National Uranium Resource Evaluation (NURE) and the Conterminous United States Minerals Assessment Program (CUSMAP) are generating tremendous amounts of geochemical and geophysical data. Satellites, such as Landsat and Magsat, provide platforms from which many other physical measurements are collected. These data are relayed back to earth in such quantities that the capacities of even the largest computers are taxed in processing them. By traditional methods of data management and evaluation, a thorough analysis of the data from just one of these programs would require tens of years to complete.

At Los Alamos, the Data Integration/Remote Sensing project is addressing such data management problems, and more importantly, the timely transformation of data into knowledge. Major goals of this project are (1) the development of automated techniques for rapid utilization of all geological data, (2) the understanding of the interrelationships of the data types, and (3) the appli cation of the derived knowledge to solution of geoscience problems. A new method of graphical presentation of data has been developed. This technique allows a rapid, visual analysis of each data set and also provides a method for viewing several data sets simultaneously. The procedure yields not only information seen in one data set, but reveals subtle features that are visible only in data combinations.

DATA AND PROCEDURES

The Montrose 1° x 2° quadrangle in west-central Colorado (approx. 19,200 sq km) was chosen as the study area to test application of data integration techniques to problems in an area of diverse geologic terrane containing various kinds of mineralization and ore deposits. The area is divided into three major physiographic provinces: the Sawatch-Gunnison crystalline terrane, the San Juan and West Elk volcanic fields, and the Colorado Plateau (Fig. 1). The Sawatch-Gunnison crystalline terrane includes the northeast third of the quadrangle and consists of Precambrian igneous and metamorphic rocks, intruded by Tertiary plutonic rocks. Central and southern portions of the quadrangle are covered by Tertiary volcanic sequences from the West Elk and San Juan volcanic centers. The western one third comprises Mesozoic sedimentary units of the Colorado Plateau. Extending diagonally across the quadrangle from southwest to northeast is the Colorado mineral belt (Tweto, 1968), a zone of precious and base metal deposits. Uranium mineralization is found at several locations within the quadrangle.

Multisource data are available for the Montrose quadrangle. The kinds of data used for this study are geochemical, geophysical, Landsat imagery, geology, and mines and mineral occurrences. The geochemical data are from the

NURE Hydrogeochemical and Stream Sediment Reconnaissance. Los Alamos completed two surveys in the Montrose quadrangle, resulting in a total of 3965 sample locations (Broxton and others, 1979; Maassen, 1981). The present study includes geochemical data for 24 of the 45 elements analyzed for in the two NURE surveys (Table I). The NURE Aerial Gamma Ray and Magnetic Survey provided the geophysical data used: equivalent thorium, equivalent uranium, percent potassium, and magnetics (geoMetrics, 1979). All four Landsat bands, from the Landsat 2 image, October 28, 1976, were incorporated. The geology was taken from the Montrose reconnaissance geologic map (Tweto and others, 1976). The 57 formations described in the Tweto report were reduced to 13 geologic units of similar age and lithology. The mine and mineral-occurrence data were compiled from Truebe (1974) and Nelson-Moore and others (1978).

The integration process presently requires all data to be at the same resolution and registration. A 1-km resolution was chosen on the basis of the geochemical sampling density. The 1-km grid was registered to Universal Transverse Mercator (UTM) coordinates. The smallest UTM rectangle containing the entire Montrose quadrangle has dimensions of 179 by 119 kilometers. Different interpolation methods were used on the various data types to obtain values for each of the 21301 grid cells, each of which contains a numerical value for each of the 34 data sets. A grid cell, as referred to in this report, represents both a 1-sq-km area of ground in the Montrose quadrangle and a series of parametric values in the Montrose data base.

The geochemical data are from sample sites that statistically are randomly spaced locations. These points are assumed to be regionalized variables. That is, they are related in some manner to the values of points some distance away--the further the distance, the less the effect (Matheron, 1963). A variogram, a plot of semivariance vs distance, is used to define the range over which the variables are interdependent and to determine a function or model that approximates the relationship. Universal kriging was employed to interpolate the value of the grid points from neighboring sample locations using the function determined by the variograms. The functions ranged from spherical, to cubic, to gaussian, to combinations of these models.

In a similar manner, kriging was also used to interpolate the geophysical data to the grid. Here, the algorithm that computes the variogram first smooths and subsamples the data along the flight line, then uses the smoothed points in the variogram computations. It was also these subsampled points that the kriging algorithm used to interpolate to the grid cells (Bolivar and others, 1981).

The Landsat data are spatially complete to 60-m resolution. After rotating and registering the image to the quadrangle boundary, these data were subsampled to the 1-km resolution using a nearest-neighbor algorithm. The geologic information was incorporated by digitizing, in three colors, a transparency made from the geologic map, then subsampling to the grid. The digitization was performed on a scanning microdensitometer. The grid cells containing mines and mineral occurrences were identified.

A common analysis technique is to overlay data sets to visually examine data for correlations. Simulating the screen of image-processing equipment, an image of each data set was generated by plotting magnitude of the value in each grid cell as intensity of light. Single data sets when displayed, show overall distributions of the values. Three data sets can be overlaid in this manner by projecting each data set in a different basic color (red, green, or blue). A computer program generated all possible combinations of three data sets and output the plots to 35-mm color slide film. This provides a permanent record of the combinations and a convenient method for viewing the correlations. This capability, not practical until now because of computational constraints, is significant because it allows all combinations to be studied. After viewing all the combinations, many relationships become apparent. Certain data patterns correlate well with a particular geologic unit. Some combinations correlate well with certain rock types. Others indicate drainage and, possibly, paleodrainage systems. Certain combinations clearly indicate structure. Three of the combination plots will be discussed. Since color reproduction is not available for this paper, black and white plots are presented. On these plots, white indicates low values and black indicates high values with 254 gray levels in between.

COPPER-LEAD-ZINC MINERALIZATION

The Colorado mineral belt, a zone containing most of the precious and base metal deposits in Colorado, extends diagonally through the Montrose quadrangle, from southwest to northeast. The mineral belt cuts across the north-northwesterly structural grain of the Rocky Mountains and may be related to a Precambrian shear zone (Tweto and Sims, 1963). Ore deposits of the belt include molybdenum, lead, silver, zinc, gold, and copper. The major mining districts in the Montrose quadrangle are indicated in Fig. 2. The combination of copper, lead, and zinc (Fig. 3) spatially defines all the major mining districts. While this might result from sampling downstream of tailings piles, there are other areas that have high copper, lead, or zinc values, but where there are no known occurrences or mines. Figure 4 illustrates this. All of the copper, lead, or zinc mines and occurrences are superimposed upon a plot of the grid cells where copper, lead, or zinc values are greater than one standard deviation above the mean (3-5% of all values). Some of the areas with high geochemical values and without occurrences can be considered favorable for mineralization.

Local background concentrations of copper, lead, and zinc are relatively consistent across the quadrangle; 90% of copper values are less than 50 ppm, 85% of lead values are less than 40 ppm, and 85% of zinc values are less than 200 ppm. When metal concentrations are elevated over small areas, they give strong indications that mineralized zones are present. In two areas north of the Lake City district, copper values are slightly elevated tc 150- 375 ppm, but lead and zinc values are higher--500-1100 ppm Pb and 1000- 1600 ppm Zn. The area along the south rim of the Bonanza caldera, south and east of the Bonanza King district, has one identified mineral occurrence. Copper values of 600-1000 ppm, lead values of 600-1500 ppm, and zinc values of 1000-4750 ppm throughout the entire area south of Bonanza King indicate more than one occurrence of mineralization. Although there may not be economic quantities of ore in these areas, it is intriguing that they have the same characteristics as the major mining districts. In contrast, the cluster of occurrences in the center of the quadrangle are adits or pits in small veins and pegmatite dikes with little evidence of profitable mining. In this area, copper, lead, and zinc values show little variation above background, which indicates no major concentrated mineralization in this region.

Another observation from the Cu-Pb-Zn combination relates to the Ouray district, in the southwest corner. Here, mines occur on either side of the Uncompahgre River, which flows northwest off the north flank of the Silverton caldera. Ores of this district were deposited in two separate periods of mineralization (Burbank and Luedke, 1968). In the earlier period, Late Cretaceous to Early Tertiary, two distinct kinds of ore were deposited. One has a pyritic/base-metal mineralogy, with silver, gold tellurides, and native gold. The other is a siliceous and baritic silver-lead ore with some ruby silver and native silver. In contrast, the Late Tertiary mineralization is associated with gold-quartz veins that contain silver and gold. The pyritic-gold ores are concentrated on the west side of the Uncompahgre River, while the silver-lead ores are mostly on the east side. The later gold-silver ores are located only on the east side. The plots of copper, lead, and zinc all show a distinct concentration change from southwest to northeast. This abrupt change corresponds with the course of the Uncompahgre River. Other elements that echo this geochemical trend are cobalt and manganese.

Considerably more information can be inferred from careful study of the Cu-Pb-Zn combination. That the mining districts are evident in this combination gives credibility to both the sampling techniques and the smoothing algorithms. The additional anomalous areas, then, are potentially very interesting. The correlation between ore mineralogy and element variations within a district promises that this technique may be useful in rapidly determining the mineralogy of areas that have not had the benefit of extensive geological exploration.

SAWATCH PRECAMBRIAN GRANITES

The Precambrian granites exposed in the northeast corner of the Montrose quadrangle are the core of the Sawatch anticline (Tweto, 1968). Superimposed on the eastern flank of this anticline is the Arkansas River graben, part of the Rio Grande Rift, which separates the granites of the Sawatch Range from the granites of the Mosquito Range. The Sawatch anticlinal region, reactivated during the Laramide orogeny, was first uplifted during the Pennsylvanian

Ancestral Rockies orogeny. Upthrown blocks are bounded by major faults that show 5,000-10,000 ft of displacement (DeVoto, 1972). One of these faults, the Mosquito-Weston fault system, is the eastern bounding fault on this portion of the Rio Grande Rift. After studying two three-element combinations (dysprosium, hafnium, scandium; and potassium, lithium, titanium) it is noticed that the granites on the east side of the rift have different trace-element compositions from those on the west side, suggesting that these two granites may be derived from different sources.

Images of these six elements are shown in Figure 5. Comparing them with the Precambrian outcrop map (Fig. 6), only one element, dysprosium, has high concentrations in both granites. Its mean value in the Mosquito Range is much higher than in the Sawatch Range (see Table II). Hafnium, scandium, and titanium have significantly higher concentrations in the Mosquito Range. Potassium and lithium have just the opposite trend, but are not as dramatically different. The crystalline province has higher average concentrations of potassium and lithium than the rest of the quadrangle. But within the province, the Sawatch Range is higher than the Mosquito Range. The variations of these six elements, and others also, cannot be fully explained by differential vertical displacement of the two granites. No interpretation is offered at this time except to suggest lateral movement along this fault system at some time. Integration of data from other quadrangles along the rift is essential before a comprehensive explanation can be proposed.

TABLE II

MEAN VALUES FOR SELECTED ELEMENTS

(all values in ppm)

Element	Sawatch Range	Mosquito Range	Quadrangle
Dysprosium	10.1	16.0	5.4
Hafnium	19.7	62.1	12.2
Potassium	21,011.0	20,248.0	17,360.0
Lithium	49.7	47.6	32.6
Scandium	11.7	19.4	10.3
Titanium	4633.0	8522.0	4774.0

CONCLUSION

At Los Alamos National Laboratory, geoscientists have integrated 34 multisource data sets for the Montrose quadrangle, Colorado and developed a computer program which graphically presents all possible combinations of three data sets. Analysis of these combinations produces information that is obvious in single data sets, <u>and</u> information that is contained only in combinations of data. Patterns observed define mineralized regions, regional geology, and suggest local mineralogy. Surprisingly, regional patterns yield new information about the character of the Precambrian granites in the Montrose quadrangle and about the structural and tectonic history of the Precambrian in the Rocky Mountains. The data integration technology described provides a new tool to rapidly analyze and interpret large amounts of data.

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TABLE I

DETECTION LIMITS AND ANALYTICAL METHODS FOR SELECTED ELEMENTS

Element	Symbol	Minimum Detection Limit (in ppm)[a]	Method of Analysis[b]
Aluminum	Al	200	NAA
Arsenic	As	5	XRF
Barium	Ba	400	NAA
Calcium	Ca	5000	NAA
Cerium	Ce	10	NAA
Cobalt	Co	2	NAA
Chromium	Cr	20	NAA
Copper	Cu	10	XRF
Dysprosium	Dy	2	NAA
Iron	Fe	2000	NAA
Hafnium	Hf	1	NAA
Potassium	K	3000	NAA
Lithium	Li	1	ES
Manganese	Mn	10	NAA
Lead	Pb	5	XRF
Scandium	Sc	0.1	NAA
Selenium	Se	5	XRF
Thorium	Th	0.8	NAA
Titanium	Ti	200	NAA
Vanadium	V	5	NAA
Zirconium	Zr	5	XRF
Zinc	Zn	30	NAA
Uranium (in sediment)	Us	0.01	DNC
Uranium (in water)[c]	Uw	0.02 (in ppb)	F

[a] Because of elemental interference, detection limits will shift as a function of sediment composition.

[b] NAA = neutron activation analysis, XRF = x-ray fluorescence, ES = arc-source emission spectroscopy, DNC = delayed neutron counting, F = fluorometry.

[c] All water samples with uranium concentrations >40 ppb are reanalyzed by DNC.

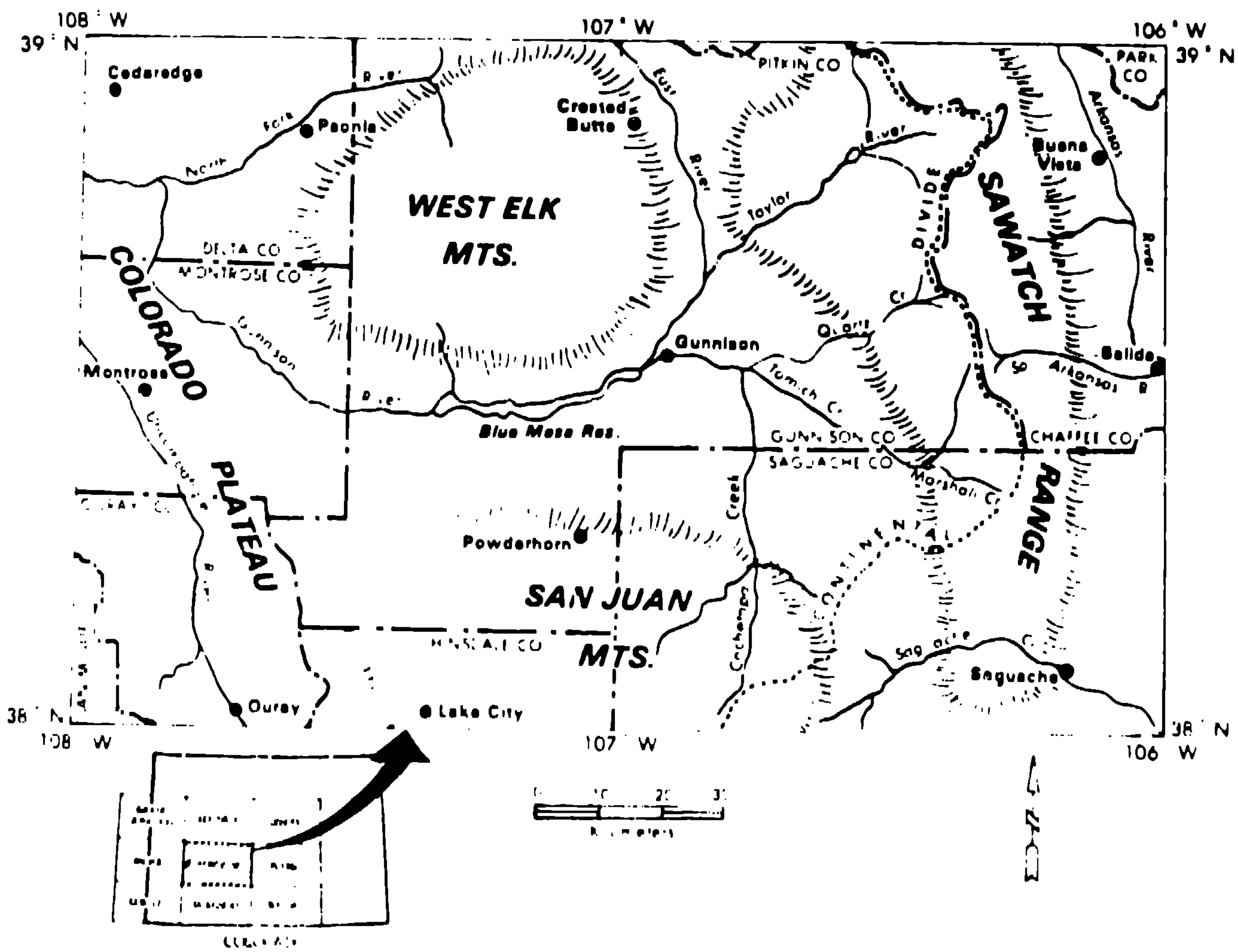

Fig.1. Location and drainage map for the Montrose quadrangle, Colorado.

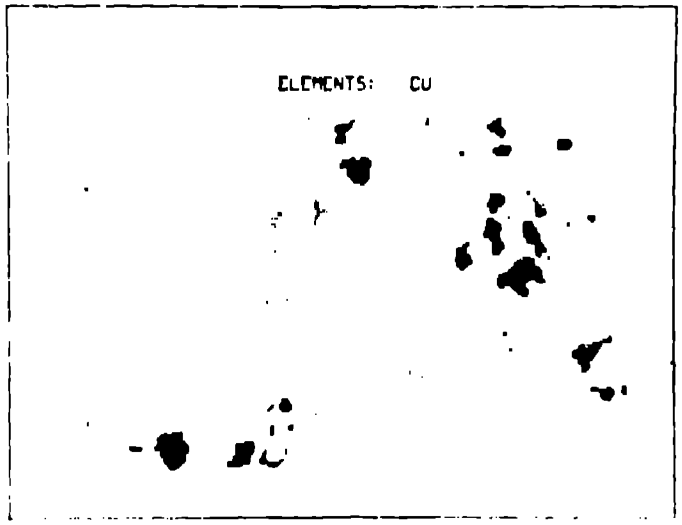

Fig.3a. Copper

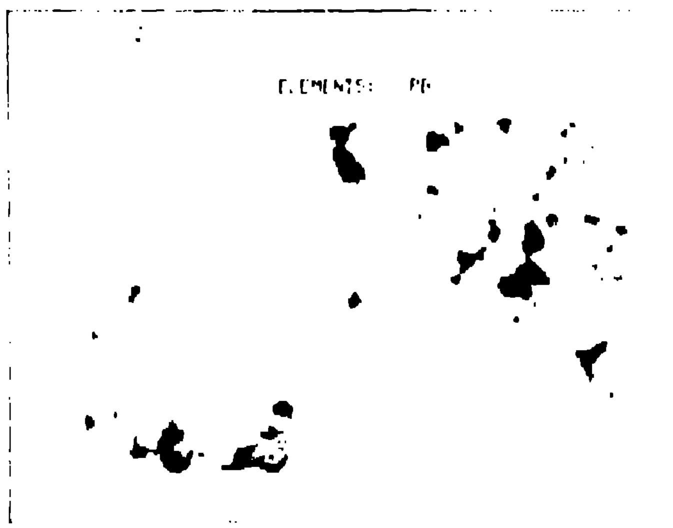

Fig 3b Lead

Fig 3c. Zinc

Fig.3. Gray-level images of kriged concentration values for the Montrose quadrangle (lowest values are white and highest values are black).

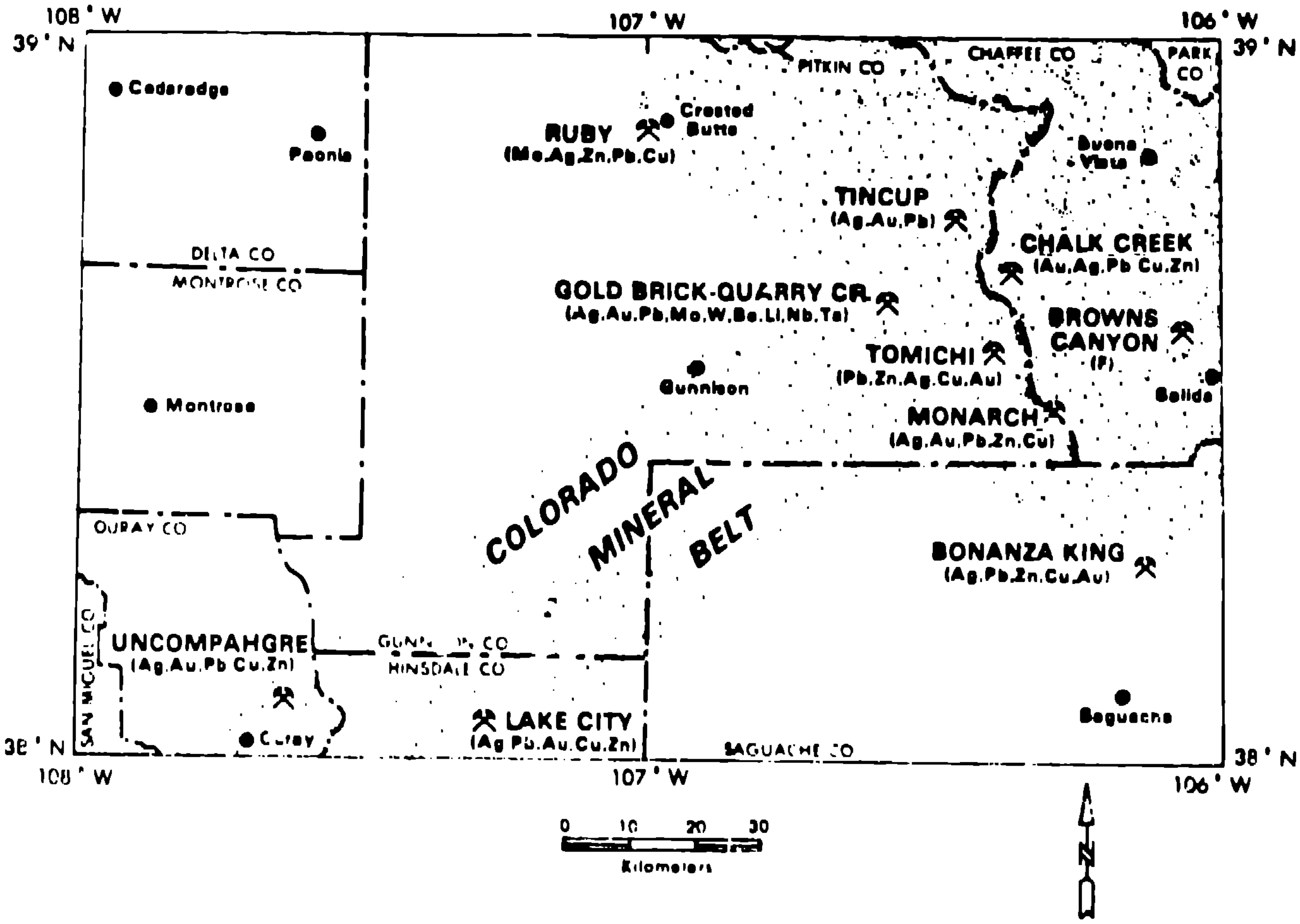

Fig.2. Major metal mining districts in the Montrose quadrangle, Colorado.

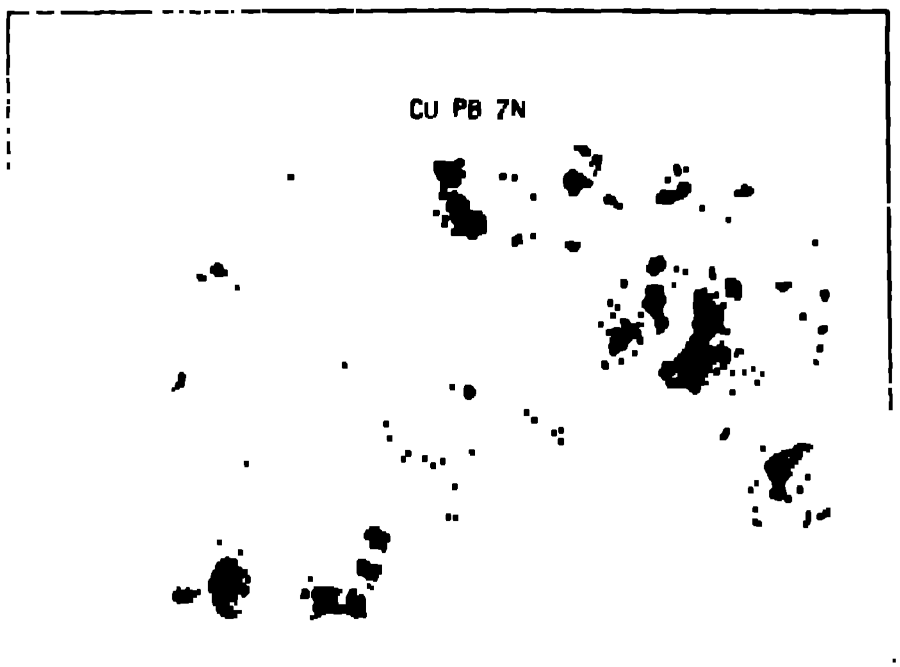

Fig. [illegible] Gray areas indicate Cu, Pb, or Zn concentration values greater than 1 standard deviation above mean (i.e., Cu>138ppm, Pb 107ppm, Zn [illegible]ppm). Star-shaped symbols mark locations of Cu, Pb, or Zn mines or occurrences.

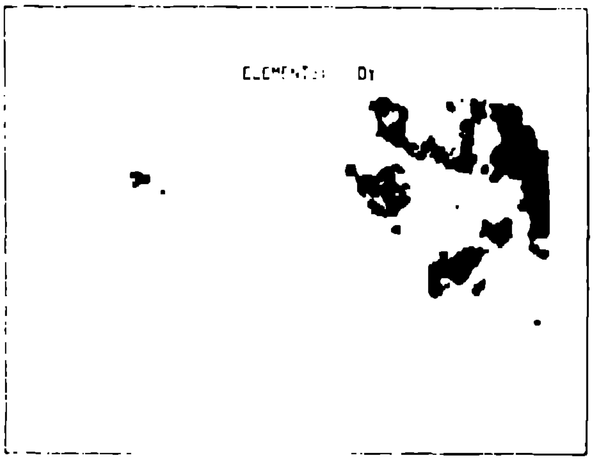

Fig.5a. Dysprosium (>8ppm).

Fig.5b. Hafnium (>21ppm).

Fig.5c. Scandium (>13ppm).

Fig.5d. Potassium (>20880ppm).

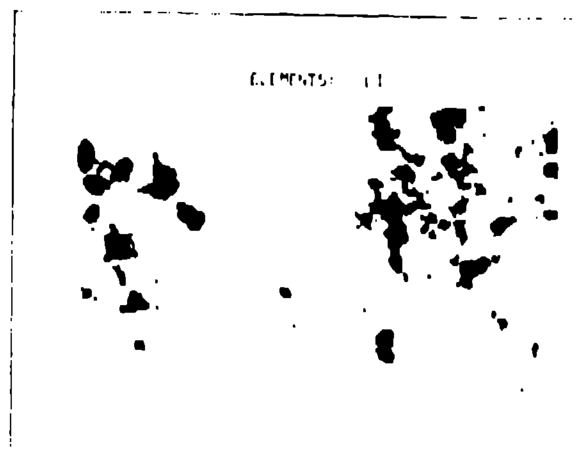

Fig.5e. Lithium (>46ppm).

Fig.5f. Titanium (>6279ppm).

Fig.5. Gray-level images of kriged element concentration values greater than 1 standard deviation above mean for the Montrose quadrangle.

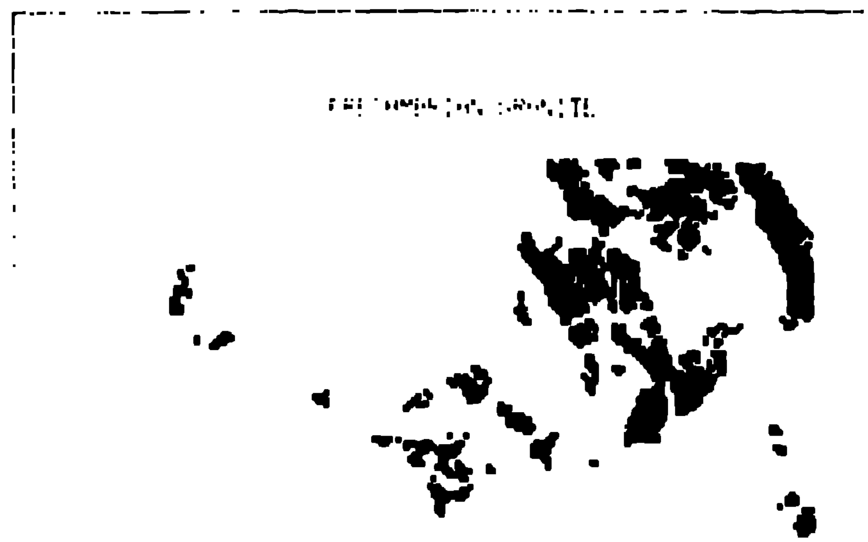

Fig.5. Outcrop map of Precambrian Granite.